

## HEAT RECUPERATOR WITH FROST PROTECTION

5        The invention relates to a heat exchanger for transferring thermal energy from a warm gas flow to a cold gas flow, comprising:

- a first group of ducts with a first connection and a second connection;
- 10      - a second group of ducts with a third connection and a fourth connection, which group is thermally coupled to the first group of ducts;
- 15      - first supply means for supplying the cold gas flow to the first connection;
- 15      - first discharge means for discharging the cold gas flow from the second connection;
- 15      - second supply means for supplying the warm gas flow to the third connection; and
- 20      - second discharge means for discharging the warm gas flow from the fourth connection.

Such a heat exchanger is generally known, but is known particularly from the Netherlands patent application number 10000706.

Such heat exchangers are usually applied for transfer of 25 gases containing water vapour. The consequence hereof is that the heat content of the relevant gas flow is not only formed by that part of the thermal energy represented by the temperature differences times the heat capacity, but also by the melting and freezing heat of water, and also by the 30 evaporation and condensation heat of water.

The first thermal content is also designated sensible heat and the second type, representing the phase change, is also referred to as latent heat. Both forms ~~of energy~~

together are also referred to as enthalpy.

The known heat exchanger is adapted to transfer the sensible heat.

In many fields of application, as a result of the 5 conditions of use, condensation and freezing of water absorbed into the gas flow usually takes place in the cooling gas flow. The freezing results in blockage of the ducts, and thereby in the heat exchanger being unusable.

The effectiveness of the heat exchanger is moreover 10 reduced because it is not possible as a result of temperature differences to transfer the latent heat resulting from condensation and freezing to the heated gas flow. The second law of thermodynamics does after all state that it is only possible to allow thermal energy to pass from a mass with a 15 higher temperature to a mass with a lower temperature.

The object of the present invention is to provide such a heat exchanger, wherein no freezing occurs and wherein latent heat is preferably also transferred.

This object is achieved in that the device comprises 20 alternating means for temporarily and repeatedly alternating in pairs the supply and discharge means on the connections.

As a result of these measures the function of the first group of ducts and the second group of ducts, the flow direction through the ducts or both are regularly alternated. 25 The above stated drawbacks are hereby avoided.

It is herein noted that the effects of the invention are most clearly apparent in heat exchangers with a direct, intimate coupling between the ducts, i.e. in heat exchangers wherein the thermal energy is transferred without storage in 30 the mass of the heat exchanger itself. Such heat exchangers are also known as recuperators.

According to a first embodiment, the alternating means are adapted to temporarily connect:

- the first supply means to the fourth connection;
- the first discharge means to the third connection;
- the second supply means to the second connection; and
- the second discharge means to the first connection.

5 In this preferably applied embodiment, the function of the first group of ducts and the second group of ducts is regularly alternated. This has the consequence that the water vapour from the gas flow which has condensed or frozen to ice in the first group of ducts is absorbed by the heating gas  
10 flow after alternating the function of the ducts. Blockage by the ice is herein reduced and then brought to an end.

15 An additional advantage is that the melting and evaporation heat in question is reused and a better thermal equilibrium results. The humidity level prevailing on the "warm" side of the heat exchanger is hereby maintained or at least hardly decreased.

20 This preferred embodiment alternates the functions of the groups of ducts. This has the consequence that a form of leakage occurs between the groups of ducts during the alternations.

25 It is possible to absorb the heat released during condensation and freezing of the water in the second group of ducts by causing water to evaporate in the first group of ducts. When the air does not contain sufficient moisture, it is possible to make use for this purpose of supply means to supply water to the first group of ducts.

30 In situations where both groups of ducts must remain strictly separated, use can be made of another embodiment wherein the device comprises means for temporarily connecting:

- the first supply means to the second connection;
- the first discharge means to the first connection;
- the second supply means to the fourth connection; and

- the second discharge means to the third connection.

The effectiveness of this embodiment is however lower than that of the first stated embodiment, so that this latter one must only be applied when a strict separation between the 5 gas flows is important.

Another embodiment teaches that the alternating means are adapted to temporarily connect the first supply means to the third connection, the first discharge means to the fourth connection, the second supply means to the first connection 10 and the second discharge means to the second connection.

According to a further preferred embodiment the heat exchanger comprises control means for repeatedly changing the connections.

The above stated measures of course have an effect with 15 a limited duration. By causing the alternation to occur repeatedly, the effects are obtained over a long and in principle unlimited period of time.

It is possible to adapt the control means to carry out the alternation at fixed intervals. It is pointed out here 20 that the results depend on the conditions, such as composition of the gas flow, for instance air which is in many cases provided with a large quantity of water vapour. The temperatures, in particular the temperature difference between the "warm" and "cold" side of the heat exchanger, are 25 of great importance here. The absolute temperature is also important in respect of processes which take place for instance both above and below the freezing point of water.

It is therefore attractive to have the alternating frequency depend on the conditions. This is achieved in an 30 embodiment wherein the alternation is carried out when a measurement value is reached. A measurement value can be understood to mean a temperature, but also a relative or absolute humidity or another variable which can be measured

at a determined location in the heat exchanger.

Although the invention is not only applicable to recuperators for use in buildings, this is however where the advantages thereof become particularly manifest.

5 The heat exchanger is therefore preferably formed by a recuperator for recovering thermal energy from ventilating air of a building.

When the construction of the recuperator is applied as described in the Netherlands patent application number 1000706, it is attractive when the first connection and the 10 fourth connection debouch in a first chamber, and the second connection and the third connection debouch in a second chamber. It is then structurally simple for the alternating means to comprise two valves, each arranged in one of the 15 chambers.

The present invention will be elucidated hereinbelow with reference to the annexed drawings, in which:

figure 1A shows a diagram of a heat exchanger according to the prior art;

20 figure 1B shows a diagram corresponding to figure 1A, wherein the connections of the groups of ducts are alternated as according to a first embodiment of the present invention;

figure 1C shows a diagram corresponding to figure 1A according to a second embodiment of the invention;

25 figure 1D shows a diagram corresponding to figure 1A of a third embodiment of the invention;

figure 2A shows a diagram of a first embodiment of the invention provided with four-way valves, during a first position of the valves;

30 figure 2B is a view corresponding to figure 2A in the second position of the valves;

figure 2C shows a diagram corresponding to figure 2A in which single valves are applied;

figure 2D shows a diagram corresponding to figure 2B wherein the valve configuration of figure 2C is applied;

figure 2E shows a diagram of the valve configuration applied in figure 2C and 2D in an alternative valve position;

5 figure 3A shows a diagram of a second embodiment of the invention in the first position of the valves;

figure 3B is a view corresponding to figure 3A in the second position of the valves; and

10 figure 4A shows a diagram of a third embodiment of the invention in the first position of the valves;

figure 4B is a view corresponding to figure 4A in the second position of the valves;

15 figure 5 is a partly broken-away perspective view of the construction according to the first embodiment of the invention;

figure 6 is an exploded perspective view of another construction according to the first embodiment of the invention; and

20 figures 7A and 7B show a diagram of a fourth embodiment of the invention.

Figure 1A shows schematically a heat exchanger designated as a whole with 1, which comprises a first group of ducts 2 and a second group of ducts 3. For the construction of such a heat exchanger reference is made to 25 the Netherlands patent application number 1000706.

It is assumed for the sake of clarity that the heat exchanger functions as a recuperator for ventilating air in a building, and that the inside of the building is designated with 4 and the outside of the building is designated with 5. 30 The ventilating air is supplied from outside by first supply means 6. Air which has passed through the first group of ducts 2 is carried to the interior of the building via first discharge means 7.

The air coming from the inside 4 of the building is supplied to the second group of ducts 3 via second supply means 8. After passing through the second group of ducts, this air is discharged to the outside again via the second discharge means 9.

The first group of ducts 2 and the second group of ducts 3 are thermally coupled to each other so that the heat relinquished by the airflow in the second group of ducts 3 is absorbed by the airflow flowing through the first group of ducts. An effective manner of heating ventilating air is thus obtained.

The recuperator described up to this point corresponds with the recuperator described in the Netherlands patent application already mentioned above.

To avoid condensation and possible ice formation at a sufficiently low outside temperature, it is possible as shown in figure 1B to reverse the function of the first group of ducts 2 and of the second group of ducts 3. A situation is then obtained as shown in figure 1B.

The first supply means 6 herein supply the outside air to the second group of ducts 3, the first discharge means 7 supply the heated air coming therefrom to the inner space 4, the second supply means 8 supply the warm inside air to the first group of ducts 2 and the second discharge means 9 supply the inside air, which has relinquished its heat, to the outside environment 5.

It will be apparent that in the situation shown in figure 1B the function of the first and second group of ducts is alternated, so that the inside air now flows through the first group of ducts through which the outside air first flowed, and vice versa. Condensation and ice formed during the situation shown in figure 1A will herein melt and evaporate again in the second group of ducts and be fed to

the inside environment. This avoids the problem of ice formation and the problems resulting herefrom, such as blockage and hygienic problems possibly resulting from a high humidity level.

5 A greater effectiveness of the heat exchange is also obtained here; the total enthalpy is transferred. The original humidity level is moreover maintained in the inside space.

10 It is possible in principle to apply other configurations; figure 1C thus shows a configuration wherein the separation of the gas flows between the groups of ducts is maintained and wherein the flow through the groups of ducts is in opposite directions. This is a possible but less desirable situation; while an improvement is obtained 15 compared to the original situation, the favourable effects are still considerably less than in the solution shown in figure 1B.

20 A similar consideration applies for the situation shown in figure 1D; different gas flows herein flow through the groups of ducts relative to figure 1A, thus obtaining the advantages of the situation achieved in figure 1B. The flow direction is in opposite direction, which is favourable per se, but which requires complicated technical provisions for the realization thereof.

25 Figures 2A and 2B show schematically an embodiment in which the regular alternation between the situations shown in figures 1A and 1B is achieved. Use is made for this purpose of two simultaneously operated valves 10 respectively 11. In figure 2A the valves 10,11 are herein placed in a position in 30 which the configuration of figure 1A is obtained, and in figure 2B the valves 10,11 are placed in a position in which a configuration of figure 1B is obtained.

Figures 2C, 2D and 2E all show an embodiment wherein use

is made of individual valves 40-47 to fulfil the alternating functions fulfilled in the embodiment of figures 2A and 2B by valves 10 and 11.

This embodiment further differs in providing a bypass 5 valve 48. This valve serves to provide an extra duct from the inside to the outside, the passage of which can be regulated.

Such a duct is attractive when the outside temperature is slightly lower than the desired inside temperature and the thermal energy generated inside is sufficient to compensate 10 the heat loss to the outside.

In the above embodiment there occurs during the alternation a temporary short-circuit which results in mixing of the mass flows. However, when a separation between mass flows is necessary, use can be made of the configuration 15 shown in figures 3A and 3B.

Use is herein made of valves 12,13. Valve 12 connects the second supply means to the first respectively the second side of the second group of ducts and connects the second discharge means to the second respectively first side of the 20 second group of ducts.

By rotating the valve 12 from the position shown in figure 3A to the position shown in figure 3B, only the flow direction inside the second group of ducts is reversed. It is nevertheless found that such a change in flow direction 25 produces an effect which is positive in respect of the above noted advantages, wherein a separation between the mass flows in the first and second group of ducts is furthermore maintained.

The configuration shown in figure 1D can also be used in 30 the same manner; the valve configurations which are possible here are self-evident.

Figure 4A shows a diagram for embodying the configuration according to figure 1D in a first position of

the valves, while this same diagram is shown in figure 4B in the second position of the valves. This diagram is less important since, even though it achieves the advantages of the invention, it does not however achieve the advantages of 5 the configurations according to figures 1B and 1C.

An example of the construction of a recuperator will now be elucidated on the basis of figure 5. In figure 5 is formed a box-like structure 14, the central part of which, 10 designated with "15", comprises two groups of ducts thermally coupled to each other. Likewise forming part of space 15 are two so-called "headers" 16, 17 respectively which ensure that the first group of ducts respectively the second group of ducts is guided to a common connection. Chambers 18, 19 15 respectively connecting onto "headers" 16,17, are arranged in box-like structure 14.

In the chamber is arranged a valve construction designated in the drawing with 20, 21 respectively. Valves 20, 21 respectively provide for distribution of the gas flows to the relevant "headers" 16,17. For supply and discharge of 20 gas flows to or from chambers 18,19 respectively, use is made of connecting pieces 22, 23 respectively, wherein there are a further two connecting pieces not shown in the drawing.

In figure 6 is shown a structure with two series of two successively placed recuperators in central part 30, the 25 corresponding connections of which debouch in ducts 31-34 which are adjacent to these connections. The ducts are connected to chambers 35,36 with valve constructions 40-47. For supply of the gas flows use is made of connecting pieces 6-9, the numbering of which corresponds with that of figure 30 2C. A simple system is obtained by coupling the valves, wherein using one size of recuperators a housing can be built for any desired volume of air by forming arrays of recuperators.

It is also possible to place a cooler in the discharge flow of the recuperator, whereby more condensation takes place in the recuperator and more evaporation can take place after alternation.

5 This principle can be further elaborated into the embodiment shown in figures 7A and 7B, which is suitable for use in for instance greenhouses.

Dehumidifying is necessary the whole year in greenhouses, since the chance of fungal growth becomes too great above 85% relative humidity. At present this takes place during the summer and winter by opening the upper windows to a greater or lesser degree. The supply of outside air by a recuperator on the one side and discharge of the moist greenhouse air on the other is already a great improvement in respect of the energy use/misuse. A drawback is then that, just as when the windows are opened, the valuable CO<sub>2</sub> content in the greenhouse decreases. In the cultivation of green plants CO<sub>2</sub> is added by heating a boiler during the day and supplying the CO<sub>2</sub> to the greenhouse, even if the heat is not required. In fig. 7A and 7B a system is drawn wherein the air in the greenhouse is dehumidified without outside air being supplied to the greenhouse or CO<sub>2</sub> disappearing from the greenhouse. Greenhouse air 8 is supplied to a recuperator 12, wherein it relinquishes heat to dried greenhouse air 7. After leaving the first recuperator 12 the air is guided via valve 11 to the second recuperator 1, in which a further cooling and condensation takes place by exchanging the heat with the outside air 6 which enters the second recuperator 1 via valve 10. The cooled and dehumidified greenhouse air is then supplied to the first recuperator 12, where heating takes place to a maximum of the greenhouse air temperature 8, depending on the quality of recuperator 12. Regular alternating of valves 10 and 11, such

that no condensation leaves recuperator 1, ensures that all condensation evaporates in the outside air 6 and that this (flow 9) leaves the greenhouse with increased humidity and a small temperature increase.

5 It will be apparent that this configuration is not only applicable in greenhouses or buildings, but that it can also be applied in other processes.

In the above described configuration the auxiliary heat exchanger is placed on the 'warm' side of the system. It will 10 be apparent that it is also possible to place such an auxiliary heat exchanger on the 'cold' side of the system or even to place an auxiliary heat exchanger on both sides of the system.

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